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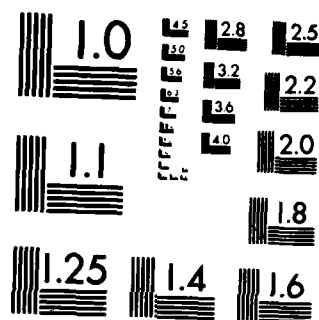
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A MODEL FOR NECK INJURY IN THE HELMETED HUMAN

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The temporal events and injury forces and energies following impact of the helmeted and unhelmeted human have not been fully described. To further advance our understanding in this area, a lumped parameter model with one-dimensional motion along the spinal axis has been developed. The muscles and ligaments and overlying tissue are assumed to offer negligible resistance in compression and the skull stiffness is neglected. Torso mass is reduced appropriately to account for the angle of impact of the person with another human or fixed object.

The lumped parameter model with springs and viscous elements representing the neck, helmet, and contact surface is given (Fig. 1a). The forces, energies, and deflection values of the various components are derived from equations previously reported.¹ Temporal displacement of the torso, head, and helmet are shown in Fig 1b. Figures 2 and 3 show the neck compression, helmet compression, head acceleration, and neck force as functions of time for the parameter values indicated in Fig. 1a. These parameter values for the model were chosen as typical values obtained from experiments and previously reported football helmet and neck studies.^{1,2,3}

All values increase with the person's velocity and weight. The neck force and energy increase with K_N , C_N , K_{HE} , C_{HE} , and K_C .⁵ The peak neck compression, neck force, and energy and head acceleration are reduced by the helmet. Initially, the greatest energy resides in the torso, the head, and the helmet. With increasing time, these values decrease while the energy is transferred to the contact spring, the helmet spring, and viscous element, and the neck spring and viscous element. The peak neck force for the exam-

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ple chosen occurs between 15 and 20 milliseconds (ms) with a corresponding neck compression of approximately 2.5 cm and a helmet compression of approximately 3 cm. It is recognized that greater forces would be transferred to the neck if the helmet bottoms out. Furthermore, as the model continues in time, the helmet rebounds and reverses its direction at approximately 67 milliseconds (ms), the head at approximately 80 ms and the torso at approximately 83 ms for the helmeted cases. The peak head acceleration occurs prior to maximum energy transfer to the contact spring, helmet and neck. This model corroborates previous studies which suggest that contact velocities of approximately 5 meters per second can produce cervical injuries.^{1,4} This model is appropriate for motorcycle, sports, and industrial helmets. However, the suitable helmet parameters must be used.

REFERENCES

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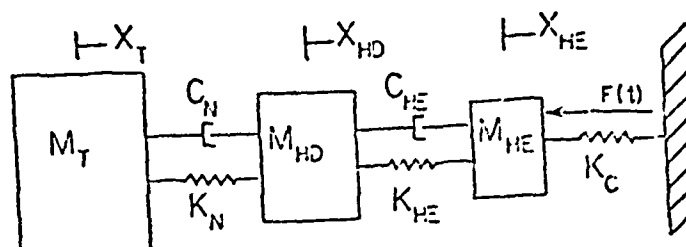


Figure 1a: Lumped parameter model where M_T = mass of thorax (kg), C_N = damping coefficient of neck (Ns/cm), K_N = stiffness coefficient of neck (N/cm), M_{HD} = mass head (kg), C_{HE} = damping coefficient of helmet, K_{HE} = stiffness coefficient of helmet, M_{HE} = mass of helmet, K_C = stiffness coefficient of contact surface, $F(t)$ = external applied force to helmet, X_T = Torso displacement, X_{HD} = Head displacement, X_{HE} = helmet displacement. Except where indicated, the values used in the model (Fig. 47-53) are $M_T = 23$ Kg, $C_N = 18$ Ns/cm, $K_N = 875$ N/cm, $M_{HD} = 4.5$ Kg, $C_{HE} = 18$ Ns/cm, $K_{HE} = 875$ N/cm, $M_{HE} = 0.7$ Kg, $K_C = 1750$ N/cm, initial velocity ($V(0)$) = 6 m/s, N = Newtons, s = seconds, m = meters, cm = centimeters.

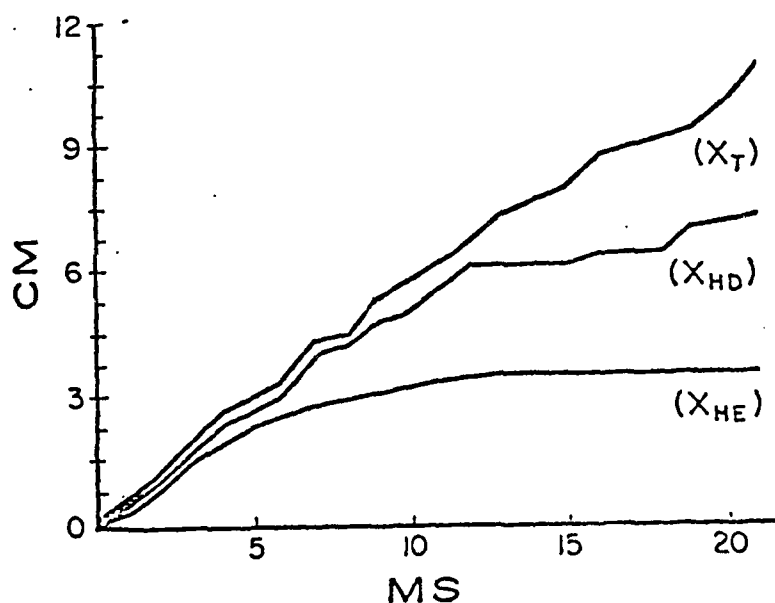


Figure 1b: Displacement of torso (X_T), head (X_{HD}), and helmet (X_{HE}) as a function of time using the parameters listed in Figure 1a.

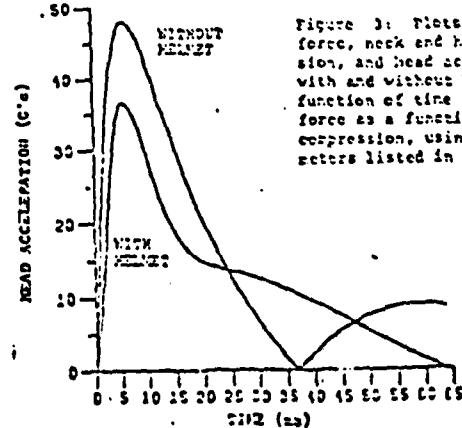
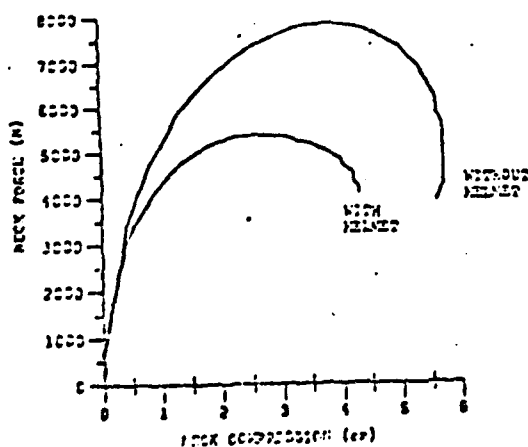
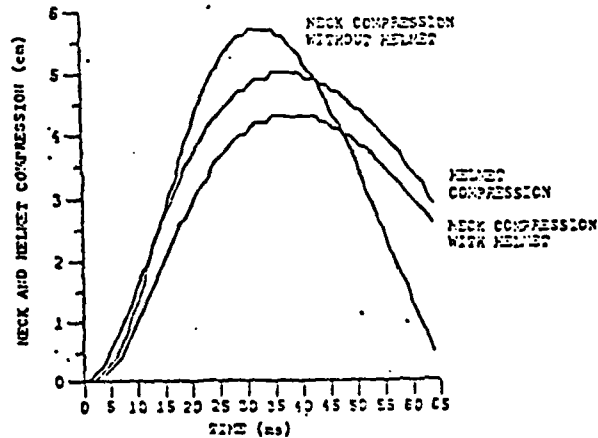
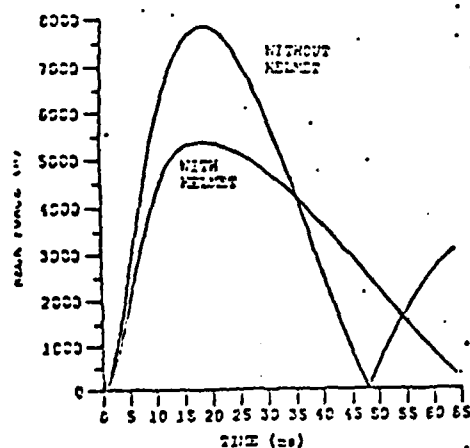
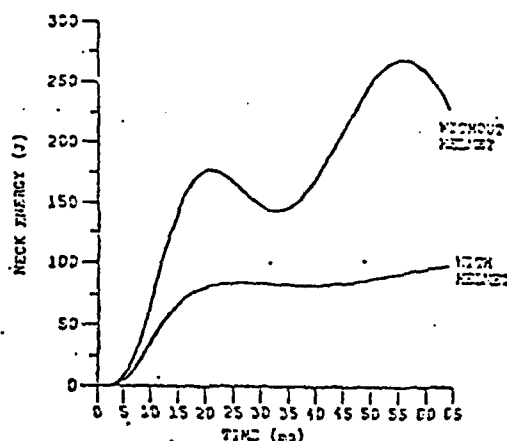
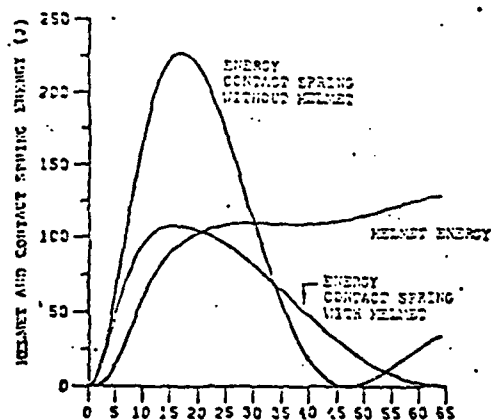
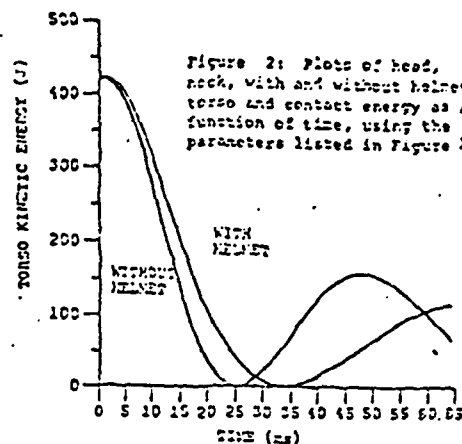
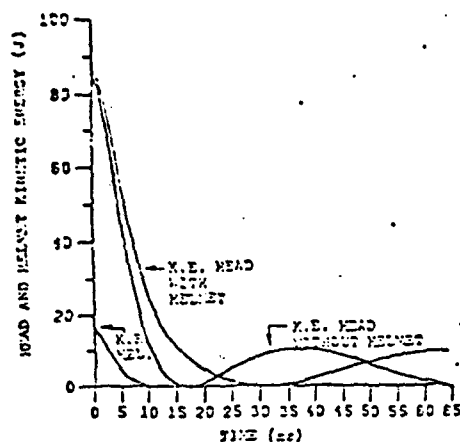


Figure 3: Plots of neck force, neck and helmet compression, and head acceleration, with and without helmet, as a function of time and the neck force as a function of neck compression, using the parameters listed in Figure 1.